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Latin American hydropower: A century of uneven evolution

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ABSTRACT

Latin America is home to a number of the largest countries powered by hydroelectricity in the world today, both in absolute and per capita levels. This region accounts for over 20 per cent of the world's hydropower and has by far the largest share of hydroelectricity over total electricity generation in the world. Excluding China, Latin American hydropower exhibits the fastest growth in the world over the last 30 years. Despite these records, Latin America's large hydroelectric potential began to be realised late in comparison to most advanced countries, and its advance has been notably uneven across time and space. This article provides a succinct survey of the evolution of hydropower for 20 Latin American countries over the past century and offers a unique quantitative, comparative perspective into the past and present of hydroelectricity in the region. We investigate the role played by the different domestic energy endowments in the way hydroelectricity developed across the region. We conclude that the gross theoretical hydroelectric potential is a necessary but not sufficient condition for understanding the historical evolution of hydroelectricity in different countries. We used panel data analysis to examine the role of alternative sources of energy, electric demand and each nation's capacity to supply electricity infrastructure. Our model explicitly accounts for the effects of different gross theoretical potentials and the effect of time passage. Overall, we report that Latin American hydropower followed an uneven path over the 20th century.

Contents

1. Introduction

As a whole, Latin America is, and has historically been, a low energy consumer region [1]. Today, the total primary energy supply per capita in Latin America is the second smallest in the world after Africa. This is also the case with electricity consumption per capita. Only Africans consume less electricity per capita. This is true despite the region having relatively large reserves of oil and, as has been recently been discovered, large reserves of coal.

Yet, there is an energy aspect in which Latin America is a world leader: hydroelectricity generation and consumption. Latin America today has by far the largest share of hydroelectricity over total

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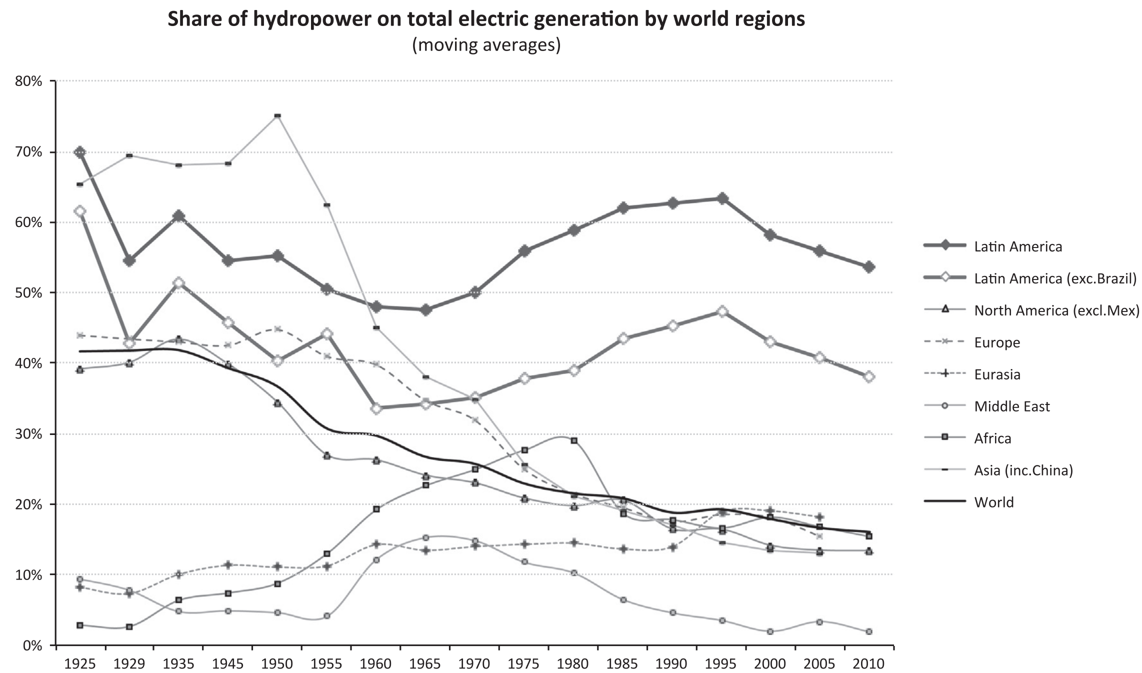

Fig. 1. Share of hydropower on total electricity generation by world regions 1925–2010.
Sources: Own elaboration from data in Dramstadter [3], pp.652ff and UN.CEPAL/ECLAC [4] (p.30) for 1925–1965 and the U.S. Energy Information Administration [5] for 1980–2007. Note that world regions are not exactly comparable between these sources.

electricity generation in the world: falling from record highs of over 60 per cent on average from the mid-1990s to 55 per cent in 2007, versus a world average of 17 per cent (Fig. 1), which has continually declined since approximately 1950.[1] Even discounting the effect of Brazil, the regional share of hydropower in total electricity generation is more than double the world average. The historical weight of hydropower in overall electricity generation in Latin America is not only larger but it also differs in that it goes against the downward global trend. While the world's average share of hydropower as part of total electricity generation fell by more than one-half during the 20th century (from approximately 40 per cent in the 1920s to less than 20 per cent in the 2000s), Latin America's share remained above 50 per cent throughout (between 35 to 45 per cent if Brazil is excluded).

As percentage of total primary energy produced, Latin America is also a world leader: hydropower, at heat value, represents on average 6 per cent of all primary energy produced in Latin America, two points above Europe, an immediate follower region. Given that most of the oil and part of the coal produced in Latin America are actually consumed elsewhere, while the hydroelectricity is consumed within, the share of hydroelectricity in the amount of primary energy actually consumed in the region – above 7 per cent in the last decade (above 5 per cent if Brazil is excluded) – almost trebles that of the rest of the world (see Fig. 2).

In historical terms, hydroelectricity is today at its maximum share of primary energy consumption in Latin America, while other countries have seen declines since the 1960s, coinciding with the commercial use of nuclear power. However, this historical progression of hydroelectric power relative to other forms of energy seems to have come to a standstill in the region over the last decade.

Moreover, hydropower continues to expand in Latin America. While in 1980 North America and Europe doubled the hydroelectricity generation levels of Latin America, by 2007 Latin America's generation surpassed both regions by an ample margin. In other words, excluding China, Latin American hydropower presents the fastest growth in the world over the last 30 years.[2] China's hydropower has gone from less than 20 per cent of total Asian hydroelectricity generation in 1980, to over 55 per cent in 2007. While it is true that Brazil has a similar role in Latin America, accounting for about half of the total regional hydroelectricity generation, the Brazilian share in Latin America hydropower generation has declined slightly over the same period (no so much in terms of consumption, however). This makes evident the rest of the region's progress, including in Paraguay, Venezuela, and Colombia, which are now among the world's 15 largest hydroelectricity generators. In fact, both China and Brazil are currently the world largest hydroelectric nations, a ranking that has historically belonged to Canada and the U.S., while Paraguay has become the world's largest hydroelectricity exporter.

These records give rise to some questions as to how they came about. Did they result from a feature shared by the whole subcontinent, or are there large differences among nations? Did it develop at a constant pace over time or was it a bumpy advance? Was the natural endowment the cornerstone of each nation's hydroelectricity generation? What was the role of demand and supply variables? This article provides concise answers for these questions, presenting the evolution hydropower for 20 Latin American countries over the past century by making use of a newly reconstructed database for the early part of the 20th century and condensing commonly scattered official information on hydroelectricity generation and consumption in a comprehensive and consistent form. These pages offer a unique quantitative and comparative long-term perspective into the past and present of hydroelectricity in the region.

A few caveats need to be introduced at the beginning. The level of analysis for such a long period and such a large number of

[1] From the 1930s to 1960, the average share of hydroelectricity as part of total electricity generation in Latin America remained about 50 per cent, Economic commission for Latin America and the Caribbean (UN. ECLAC/CEPAL) [2] Table 11.

[2] Data for Figs. 1 and 2 were rearranged so that Mexico is included in Latin America rather than in North America.

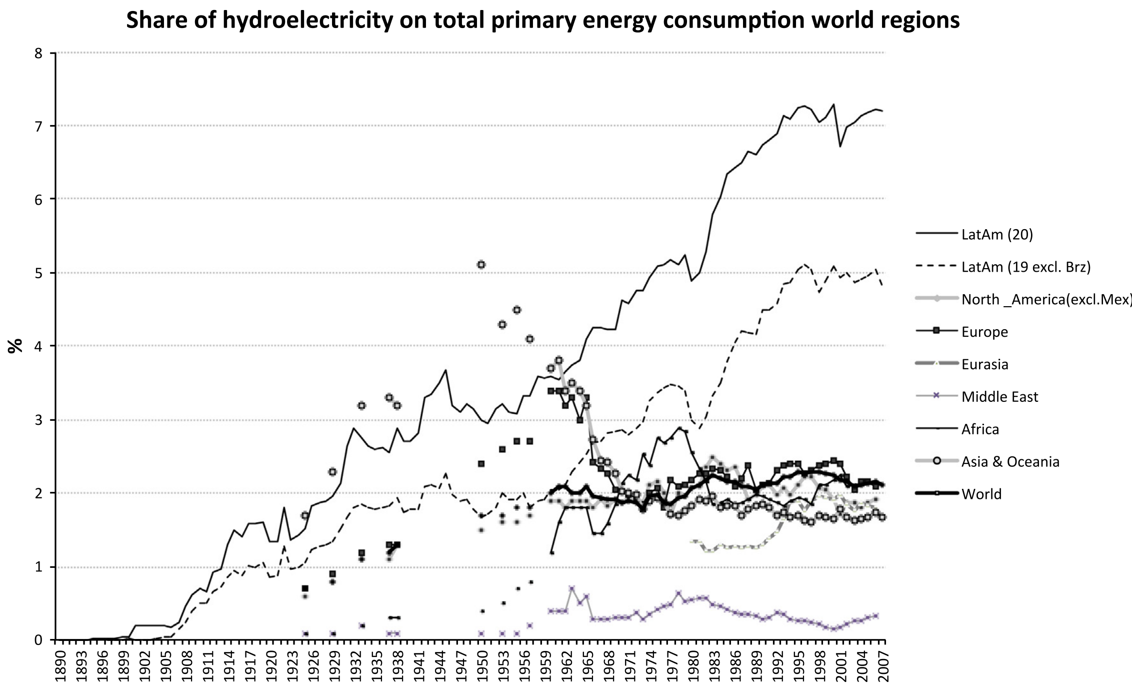

Fig. 2. Share of hydroelectricity in primary energy supply, world regions 1890–2007.
Sources: Dramstadter [3] pp.652ff for 1925–1965 (except Latin America) and U.S. Energy Information Administration [5] for 1980–2007. Note that world regions are not exactly comparable between these two sources. Latin America 1890–1980 is a three years moving average of the 20 countries in the Appendix B, and the same 20 countries three years moving averages from U.S. EIA 1980 onwards.

countries needs to remain at the macroscopic level. It would be impossible to offer a regional overview while offering specific national and/or sectorial descriptions given the space limitations of a single article. To gain a regional perspective, detailed country analyses are necessarily forgone. Hydropower is not free of ecological impacts, even if they played a minor role in past decisions regarding hydropower and are neglected in our analysis. For most of the paper, consumption and generation of hydroelectricity are used interchangeably. For approximately 80 years, this is a rough approximation – notwithstanding transport losses – but it is generally correct. For the period after 1980, however, when international grids become meaningful and hydroelectricity started to be massively exported and imported in the Southern Cone, we make a more careful distinction of the two.

2. Latin American hydropower: A long-term perspective

In the literature confined to post-1960 data, there is a lack of long-term series on the relationship between energy, economy and greenhouse gas emissions, either from energetic, ecological or environmental standpoints. In fact, most studies focus on a single country or region over time (generally short periods, from 10 to 20 years), or conduct cross-country analyses of benchmark years of a set of countries. Few long-term series (over a century or more) of energy consumption have been elaborated, and until very recently they belonged exclusively to advanced economies.[3] There are two major compilations of long-term energy statistics aiming to provide a global perspective: Darmstadter et al. [3] and Etemad and Luciani [16]. Neither of these covers enough ground in space or time in relation to developing countries.

The first hydroelectric power plant was installed in England in 1870, while the first industrial use of hydropower started in the early 1880s in the U.S. The earliest notices of hydropower generation in Latin America appeared in the very same decade. Pioneer countries in the region were Brazil and Costa Rica, although for most of the first decades hydroelectric developments were chiefly connected with mining enterprises in Mexico, Chile, Peru and Bolivia. Although national and local studies are relatively abundant on the subject of hydroelectricity generation, until very recently no comprehensive quantitative work was available for the period before the 1930s [17,18] and the overall coverage of the region remained very patchy until the 1960s when official international statistics widened in their scope and depth. Even for relatively recent decades the information about hydroelectricity generation and consumption in Latin America is usually scattered or private (OLADE, IEA, etc). The data in this article overcome all of these issues and offer a complete view of the development of hydropower in Latin America over more than 100 years making use of a newly reconstructed annual database for the early part of the 20th century and condensing official information in a comprehensive and consistent form for the second half of the century, as explained in Appendix A. In total, our dataset covers 20 countries (all the republics but not the colonies and territories) for the period from the 1900s to 2005.

The evolution of hydroelectricity generation, in absolute terms, signals the landmarks and the leading nations in Latin America. Brazil was the pioneer country in making use of its huge hydraulic resources, but it has also historically been the largest generator and consumer of hydroelectricity in the region for over a century: over half of the hydropower on the subcontinent has historically been based in Brazil (see Table 1). Brazil's position has remained unchanged and unchanged since the 19th century, while the rest of the ranking experienced more variations. Up until the

[3] Austria: Krausmann and Haberl [6]; Canada: Steward [7]; Italy: Malanima [8]; Japan: Hunt and Ninomiya [9]; Netherlands: Gales et al. [10]; Spain: Rubio [11]; Sweden: Kander [12]; the United Kingdom (UK): Fouquet and Pearson [13]; Warde [14] and the United States: Schurr and Netschert [15].

Table 1
Shares of each Latin American country on the total regional hydroelectric consumption.
Sources: See Appendix A. See Appendix B for the actual data series.

Shares of each country on total regional hydroelectric consumption

	Argentina (%)	Bolivia (%)	Brazil (%)	Chile (%)	Colombia (%)	Costa Rica (%)	Cuba (%)	Ecuador (%)	El Salvador (%)	Guatemala (%)	Haití (%)	Honduras (%)	Mexico (%)	Nicaragua (%)	Panama (%)	Paraguay (%)	Peru (%)	Rep.Dom. (%)	Uruguay (%)	Venezuela (%)
(%, 5 years moving averages)																				
1900			92	4		4														
1910	2		47	13	0	1	0	0	0	0		0	34				3			0
1920	3	0	48	14	1	1	0	0	0	0		0	29				3			0
1930	3	1	47	12	3	1	0	0	0	0		0	28				4			1
1940	2	1	45	12	4	1	0	1	0	0		0	27				6			1
1950	1	1	52	12	5	1	0	1	0	0		0	16	0			5		3	1
1960	3	1	54	9	7	1	0	1	1	0		0	15	0	0		5	0	2	1
1970	2	1	51	6	6	1	0	1	1	0	0	0	19	0	0	0	5	0	2	5
1980	7	1	58	3	7	1	0	0	0	0	0	0	9	0	0	0	4	0	1	7
1990	9	0	58	3	6	1	0	1	0	1	0	0	6	0	1	1	3	0	1	10
2000	9	0	58	3	5	1	0	1	0	0	0	0	5	0	0	1	3	0	1	10

1940s, Mexico accounted for between one fourth and one third of the hydroelectricity generated and consumed in Latin America, with Chile following with about half of that share. In other words, for the first third of the 20th century, over 90 per cent of all hydroelectricity in Latin America was concentrated in only three countries: Brazil, Mexico and Chile.

The following decades saw some changes in the secondary positions. Colombia and Peru, which until the mid 20th century maintained a share of 3 to 5 per cent of the regional total, doubled their generation capacity. Thus, their consumption of hydroelectric power achieved levels of 7 to 8 per cent of regional consumption. Uruguay commissioned its first hydroelectric plant by 1944; Argentina almost quadrupled its installed capacity in the 1950s; and Venezuela increased its generation capacity over thirty times between 1960 and 1969. During the 1970s, four countries matched the generation levels of Chile, quickly progressing towards Mexican levels. All over the subcontinent, dams were being constructed or planned. Consequently, the consumption of hydroelectric power in Latin America more than doubled every decade from 1940 to 1970. The weight of the three largest country generators was progressively reduced, although by 1970 they still accounted for 75 per cent of the regional total. However, as a whole, Latin America was still a small player with approximately 6 per cent of the world's total hydropower generation.

The oil crisis brought about intensive changes in Latin American economies and affected the way in which electricity was generated. By the late 1930s, Latin America had almost abandoned coal burning, relying almost exclusively on oil for thermal electric generation [19]. With the exception of oil producing countries, burning oil had suddenly become almost unaffordable by the 1970s. At the time, hydroelectricity generation seemed to be the only obvious alternative in most countries, and the rush to exploit water flows even further continued to expand. Some of the most significant advances took place in countries where hydroelectricity had only begun the decade before. Panama saw its hydropower grow at an astonishing 40 per cent per year on average from 1970 to 1980; the Dominican Republic at 22 per cent; Honduras at 15 per cent; and Paraguay at 13 per cent. Large generators were also able to increase their hydropower further. Argentina expanded its hydroelectric consumption by 27 per cent annually over the decade, Colombia by 15 per cent and Brazil by 12 per cent. As a result, hydroelectric power generation and consumption almost trebled in Latin America from 1970 to 1980, growing at an average rate of 10 per cent annually. It grew faster than any other place in the world, doubling Latin America's share in the world's hydroelectricity generation to over 12 per cent by 1980.

The 1980s are usually referred to as the "lost decade" in Latin America following the slump created by the debt crisis. However, in terms of hydropower, the 1980s brought about crucial developments in the form of joint ventures that had been planned over previous decades. The most famous was Itapu (Paraguay–Brazil). In fact, it was second in history to Salto Grande (Uruguay–Argentina), followed by Yacyretá-Apipé (Paraguay–Argentina). All three were government enterprises. Consequently, by the 1990s, the distinction between hydroelectric consumption and generation became important in the Southern Cone. For example, Paraguay exported on average 90 per cent of its hydroelectricity to Brazil and Argentina.

How can we classify Latin American countries according to their pattern of hydroelectric development in the long term? Making use of total generation and generation per capita figures, it is relatively easy to group countries given their historical paths. First, observe the level of hydroelectricity generation per capita (see Fig. 3). Our data reveal that 12 countries (out of 20!) have always had per capita generation levels below the regional average. These countries, which could be classified as undersized,

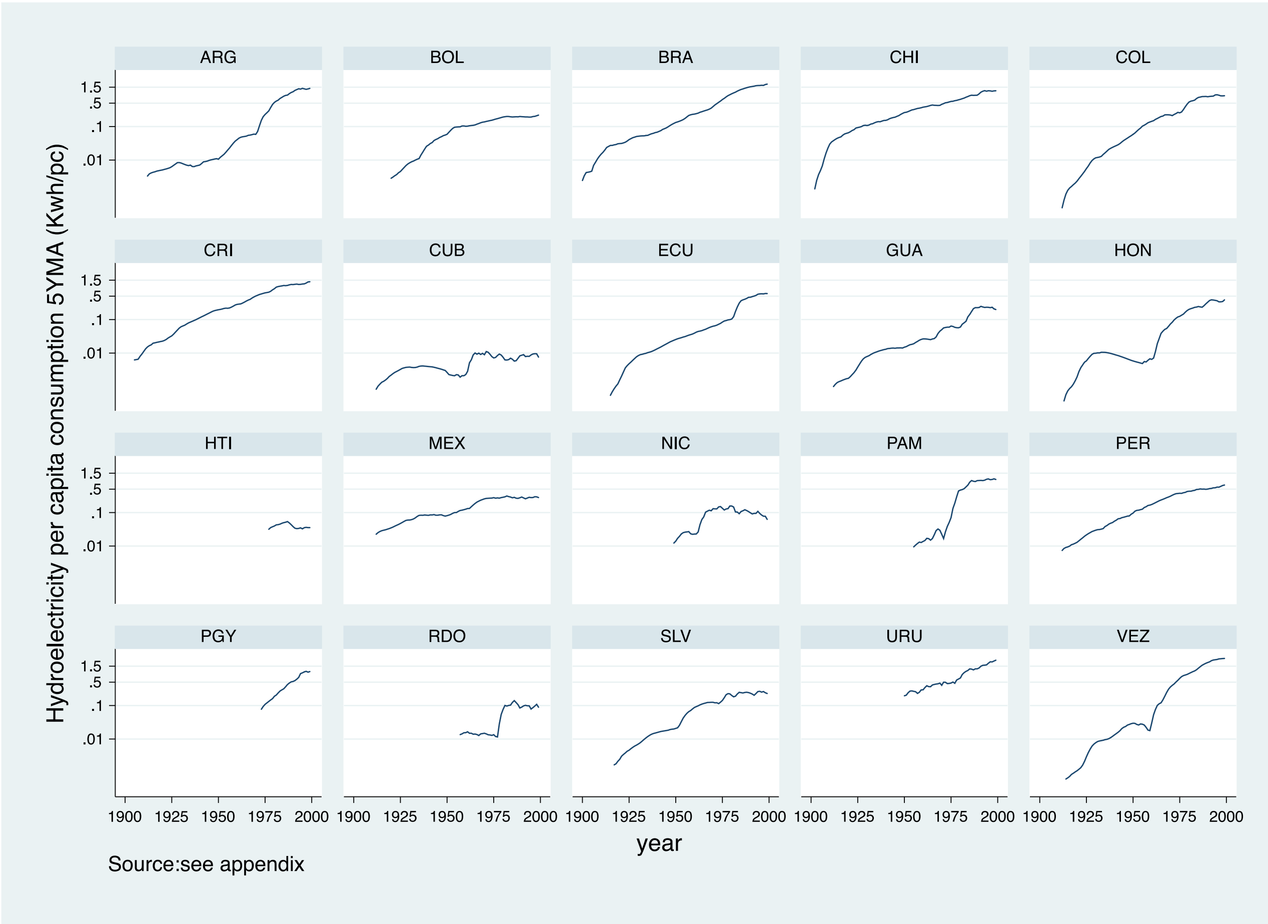

Fig. 3. Hydroelectricity per capita consumption in Latin America 1900–2000 (five years moving averages kW h per habitant).
Source: See appendices.

are in ascending order starting from the smallest: Cuba, Haiti, Dominican Republic, Nicaragua, Guatemala, El Salvador, Bolivia, Honduras, Ecuador, Panama, Paraguay and Colombia. Another country, Peru, could be added to this list, as it was below the regional average for most years in our study (although it was above the average from 1940 to 1975). It is important to keep in mind that the aforementioned countries did not follow the same growth path with hydroelectricity generation. Although they share a relatively small size of hydropower, they should be reclassified according to their growth paths. Before considering this issue, however, we will analyse the features of the remaining countries (Table 2).

Historically, the seven countries with a relatively larger hydroelectric development took off from the regional average at very different times. Attending to the broad periods described above, the countries could be classified as early adopters, intermediate adopters, and latecomers. Those countries whose levels of hydropower generation per capita were well above the regional average over the first four decades of the 20th century were clearly early adopters. Those that took off from 1940 to 1980s were intermediate adopters. Finally, only those exceeding the regional average from 1980 are latecomers. To the pioneer countries mentioned above – Brazil, Chile and Mexico – we must add now Costa Rica as an early adopter. Its levels of per capita generation remained at the top of the region for the longest time. Of these, only Mexico lost its preeminent position. Beginning in 1950, Mexico's hydroelectricity production per capita fell below the regional average. The intermediate level contains Uruguay and Venezuela. Both overtook the leading position of per capita generation of early adopters in the last years due to the fast growth of the installed capacity over the period from 1980 to 2000. Finally, Argentina deserves a class on its own as a latecomer. Beginning only 1980 its hydroelectric consumption per habitant is above the regional average.

Coming back to the larger group of countries with a relatively undersized hydroelectric sector, it is necessary to outline some differences among them. Paying attention to the growth of their hydropower generation over the 20th century they could be regrouped in at least two subgroups. In the first subgroup are the countries that, despite having a relatively small generation of hydroelectricity, managed to make it grow faster than Latin America as a whole. Here we clearly find Ecuador, Honduras and Peru, where total generation grew faster than the regional average in each of the three sub-periods. Nevertheless, all three remain below average in kW h per habitant because their production levels initially were really minuscule compared with the average. Within this group of undersized but fast growing hydroelectric countries, we can also place Colombia, whose generation grew faster up until the 1980s, and matched the regional pace from then onwards. Guatemala also grew in keeping the average until 1980, but faster thereafter. Bolivia, Panama, Paraguay and the Dominican Republic behaved mostly similar to Colombia, but they began generating hydroelectric power much later in the middle of the 20th century, or, as in the case of Paraguay, very late in the 1970s. In the second subgroup among the undersized countries are those which, in addition to relatively small hydroelectricity generation, had very weak expansion – approximately 1 per cent per year – in

Table 2
Classification of Latin American nation according to their hydroelectric development 1900–2000.

	Relative level of development **hydroelectric generation per capita**	Growth rate of the **total hydroelectic generation** (relative to the regional average)
Argentina	Latecomer	1907–1940 =; 1940–2000 >
Bolivia	Undersized	1915–1940 >; 1940–2000 =
Brasil	Early adopter	1900–1940 =; 1940–2000 >
Chile	Early adopter	1900–1940 >; 1940–1980 =; 1980–2000 >
Colombia	Undersized	1907–1980 >; 1980–2000 =
Costa Rica	Early adopter	1900–1940 =; 1940–2000 >
Cuba	Undersized	1907–1940 =; 1940–2000 <
Ecuador	Undersized	1910–2000 >
El Salvador	Undersized	1912–1980 >; 1980–2000 <
Guatemala	Undersized	1907–1940 =; 1940–1980 =; 1980–2000 >
Haiti	Undersized	1980–2000 <
Honduras	Undersized	1908–2000 >
Mexico	Early adopter	1907–1980 =; 1980–2000 <
Nicaragua	Undersized	1944–1980 >; 1980–2000 <
Panama	Undersized	1950–2000 >
Paraguay	Undersized	1980–2000 >
Peru	Undersized (except 1940–1970)	1907–2000 >
Dominican Rep.	Undersized	1952–1980 >; 1980–2000 =
Uruguay	Intermediate	1945–1980 =; 1980–2000 >
Venezuela	Intermediate	1907–2000 >

Key:
Relative level of development: Early adopter: above regional per capita generation from 1900–1940; Intermediate: above regional average from 1940; Latecomer: above regional average from 1980; Undersized: permanently below the regional per capita generation average.
Total generation growth rate: = same as the regional growth rate; < inferior to regional growth rate; > superior to regional growth rate (allowing ± 0,0/1,0 points on the allocation to each category).

Table 3
Water power potential in Latin America through history 1920s–2000s.

	1928 (GW)	***1954*** (GW)	***1962*** (GW)	***2009*** (GW)
Argentina	6.7	29.4	30.0	40.4
Bolivia	3.4	22.8	22.5	20.3
Brazil	34.9	176.6	180.0	260.3
Chile	3.4	18.4	26.6	25.9
Colombia	5.4	73.6	75.0	114.2
Costa Rica	1.3	5.9	6.0	25.5
Cuba	0.0	0.0	0.0	0.3
Ecuador	1.3	25.7	26.5	18.9
El Salvador	0.3	1.1	1.1	0.8
Guatemala	1.7	8.8	9.0	6.2
Haití	0.0	0.0	0.0	0.5
Honduras	1.3	5.9	6.0	1.8
Mexico	8.0	33.1	33.8	49.0
Nicaragua	1.1	4.4	4.5	3.7
Panama	0.7	2.9	3.0	3.0
Paraguay	2.7	7.3	7.5	12.7
Peru	6.0	40.4	41.3	180.0
Rep.Dom.	0.0	0.0	0.0	5.7
Uruguay	0.4	2.2	2.5	3.7
Venezuela	4.0	36.8	37.5	83.4
Total LATAM20	82.6	495.3	512.7	856.2

Notes and Sources: Data for year 1928 from Bradley [22] pp.44 refer to 'water power potential', thousand horse power in the original converted here. Data for year 1954 from United Nations, Economic Commission for Latin America and the Caribbean (UN. ECLAC/CEPAL) [4] although originally from the USGS. Data for 1962 from the USGS reported in Young [20] pp.8–12. These two figures respond to 'gross theoretical potential' at average flow. Data for 2009 from [22] except for Cuba, Guatemala and Haiti for which data are for year 2005 from International Copper Association (ICA) [23] (Table 1, p. 21).

Table 4
Relative gross theoretical potential 2009 (GW h/km^2).
Sources: As 2009 in Table 3 divided by the official size of each country.

Costa Rica	4.38
Peru	1.23
Rep.Dom	1.03
Colombia	0.88
Venezuela	0.80
Ecuador	0.62
Guatemala	0.54
Chile	0.37
Brazil	0.36
Panama	0.34
El Salvador	0.33
Paraguay	0.27
Nicaragua	0.25
Mexico	0.22
Uruguay	0.18
Bolivia	0.16
Haiti	0.14
Honduras	0.14
Argentina	0.13
Cuba	0.03

the long term or were even null from 1980: Cuba, El Salvador, Haiti and Nicaragua. The latter is the only Latin American country where hydroelectricity generation and consumption dropped.

These differences across the continent in the development of hydroelectric power reflect different natural endowments. Yet, as we try to prove through the rest of the article, having water flows is a necessary but not sufficient condition for developing hydropower. A domestic endowment of alternative sources of energy may alter the development of hydropower; a lack of demand may hinder the development of existing water flows into hydroelectricity. Even if water flows and demand exit, someone must pay for the dams, so supply factors may also play a role.

3. Natural endowment: Necessary but not sufficient

Hydropower potentials have been published on a regular basis since the industry's beginning: the United States Geological Survey

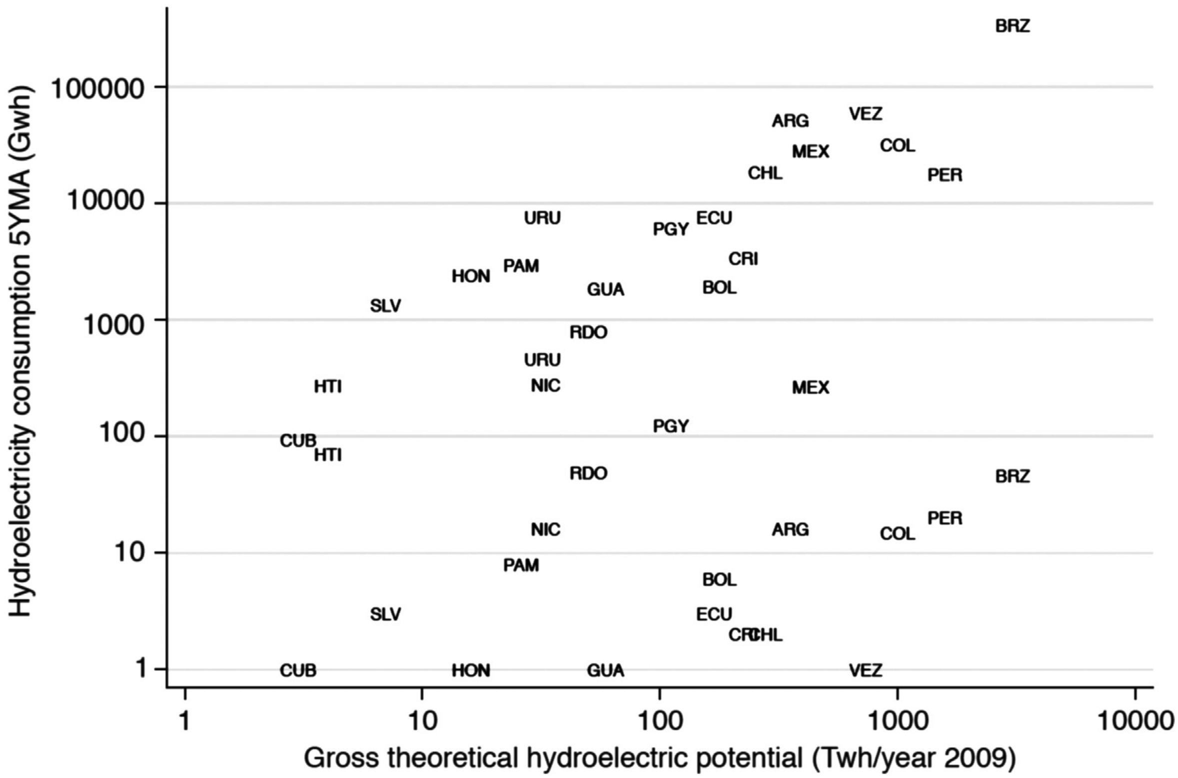

Fig. 4. Gross theoretical hydropower potential vs historical hydroelectric consumption in 20 Latin American countries. (Initial and last level of consumption over the 20th century 5-year moving averages).

Sources and Notes: Gross theoretical hydropower for year 2009 in Table 3 (above); Historical hydroelectric consumption see data appendix. For each country, the uppermost dot represents the year 2000 5-year moving average (averaging consumption from 1998 to 2002), the lower dot depends in each case of the starting of the hydroelectric production, which can be verified on the data appendix.

first made an estimate of the potential waterpower of the United States in 1908 and of the world in 1918 [20]. Potential has typically been categorised as gross theoretical, technically feasible or economically feasible. The science behind each of the indicators has changed substantially over the past century, and even today, there exists considerable debate regarding the quantification and classification of the world's hydropower resources.[4] Notwithstanding the flaws, we should attempt to assess the different natural endowment of water flows in Latin America historically using the more encompassing definition of gross theoretical potential.

Successive approximations of Latin America's gross theoretical hydroelectric potential have increased the gross potential tenfold from the 1930s to today, as shown in Table 3. Some of the key players were already identified very early on despite the insufficient science and technical means of estimation many decades ago. The super endowment of Brazil, for instance, which is double that of the runner up – Peru – was patent from the earliest estimations. At the other end, the country with the smaller absolute hydroelectric potential is Cuba, as it is the case of most of Central America apart from Costa Rica. In absolute terms, the distance between the best endowed – Brazil – and the rest of the region is abysmal: of the 19 countries, 14 do not reach 10 per cent of Brazil's potential, and 9 of them are below 2 per cent.

This absolute measure of the hydraulic endowment ignores the republics' different sizes. Some small nations are relatively well endowed with water flows, but this will not be evident in the shadow of Brazil's massive potential. In the same vein distance matters in electricity transportation; beyond a certain distance, transportation is not worth it. In fact, at the beginning of the twentieth century, it was not even feasible to transport electricity more than few hundred meters. For these two reasons, it makes sense to calculate a relative measure of waterpower potential endowment: gross theoretical potential per square kilometre.

In relative terms (see Table 4), there are two clear outliers in the regions: Costa Rica with a relative potential three times larger than the second in the ranking – again Peru – and Cuba, which even in relative terms falls way behind the rest of the continent. The rest of the region overlaps in a range from 0.1 to 1 GW h/km^2. Per square kilometre, the hydroelectric potential of Brazil matches that of Chile, but it is half that of Ecuador, Venezuela or Colombia.

Did all countries take equal advantage of their theoretical hydropower potential? Ignoring technical and economic constraints we could say that the gross theoretical potential estimated in 2009 was already present in 1900; it is reasonable to say that geography and average rainfall were constant through the century, that is their natural endowment has not changed. As economic and technological conditions evolved, each country went about translating existing water flows into hydroelectricity over the course of the century. Fig. 4 plots the theoretical potential of each country versus the actual hydroelectricity consumed, while Fig. 5 shows the relative potential per square kilometre versus the actual hydroelectricity consumed per capita. In both cases we provide the consumption data for the initial level of hydroelectric generation at the earliest possible date and the latest year of the 20th century for which a 5-year moving average is available. The uppermost dot

[4] 'Theoretical potential can be measured in various ways, for example, from the theoretical energy associated with precipitation falling on the land surface to a summation of the sites that have been assessed within the national territory. Technical potential is increasingly challenged as it tends to be based only on specific sites and tends to exclude other sites that could be developed. Economically feasible potential is also questioned on the basis that much of the evaluation is based on energy prices at different times in the past, again tending to underestimations.' [21] pp. 289–290.

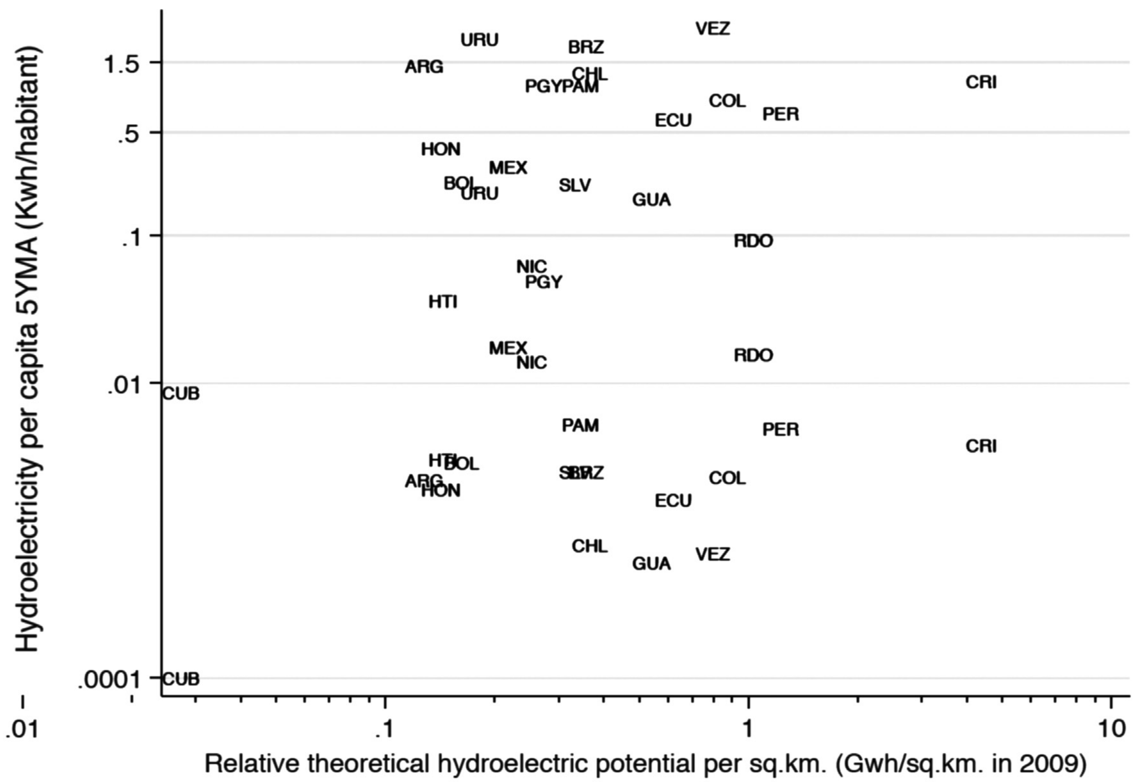

Fig. 5. Relative theoretical hydropower potential vs hydroelectric consumption per capita in 20 Latin American countries. (Initial and last level of consumption over the 20th century, 5-year moving averages).
Sources and Notes: as in Figure 5. Square kilometers as nationally reported. For each country, the uppermost dot represents the year 2000 5-year moving average (averaging consumption from 1998 to 2002), the lower dot depends in each case of the starting of the hydroelectric production, which can be verified on the data appendix.

for each country corresponding to the year 2000 averaging consumption from 1998 to 2002, the lower dot depends in each case of the starting of the hydroelectric production, which can be verified on Appendix B. The level of hydroelectricity consumption for each country moved within those two points along the 20th century.

Assuming that natural endowment was all that mattered, hydroelectricity should have developed first and more importantly in those countries with the best endowment in absolute and relative terms, that is, Brazil, Peru, Colombia and Venezuela—rather than in Brazil, Mexico and Chile as it happened. In terms of performance, except Brazil, the best-endowed nations – Mexico, Chile, Peru and Colombia – underperformed according to the classification made in the previous section. Uruguay, Nicaragua and Panama all have similar gross theoretical potential and similar relative endowments, yet the timing and intensity of the hydroelectric developments in all these countries was different over the 20th century as observed above. Among the worst endowed, Guatemala consumed far less hydroelectricity –total and per capita – at any given moment in time, than for instance El Salvador, a country with a lower absolute and relative potential. Hydroelectric potential seems to be a necessary but insufficient condition to explain the individual historical advance of hydroelectricity generation in Latin America.

4. Alternative sources of energy, demand and supply factors explaining hydropower

Latin American countries differ greatly in the potential for hydroelectricity generation but also in other natural resources, including fossil fuels. Six Latin American countries were oil and/or gas producers already by the 1920s – Argentina, Colombia, Ecuador, Mexico, Peru, and Venezuela – later adding Brazil and Bolivia. Mexico and Venezuela historically led world oil exports at different times [24].[5] Regional oil production historically exceeded its consumption. By contrast, coal endowment was much smaller. Only Chile produced meaningful amounts by the mid-19th century. Argentina, Mexico, Peru and Venezuela only covered a small part of their consumption with domestic coal. Only recently Colombia and Brazil became major coal producers and exporters [25].

Having fossil fuels in one territory may affect overall decisions regarding a country's energy mix. Given two countries with identical hydraulic potential but different fossil fuel endowments, our initial hypothesis is that the one without fossil fuels will develop its hydroelectric power faster given its lack of alternatives.

Yet, possessing a rich natural endowment – whether hydraulic or fossil – does not necessarily imply a country will make use of it. Lack of demand may hinder the development of existing water flows into hydroelectricity; and even if water flows and demand exit, someone must pay for dams and distribution infrastructure. Urbanisation rates are widely recognised as a major driver of energy demand [26], and of electricity demand in particular the long- and short-term in any economy. In Latin America this is even more the case given that historically electricity consumption by domestic users in urban centres surpassed that of productive industrial users [27,28]. Therefore, our hypothesis is that countries with larger urban populations will have greater incentives to develop their water resources into hydroelectric power than countries with prominent rural or scattered populations.

[5] Tinidad & Tobago was also producing oil in the 1920s, but it is not included in our sample.

Who paid for the electric infrastructure varied across time and space? The evidence is not specific for hydroelectric infrastructure but Hausman et al. [29] (pp. 31–33) provided a glimpse of its changing nature for the overall electricity sector. They provide few benchmarks for the percentage of electric utilities owned and controlled by foreign firms from 1900 to 1970. Their evidence suggests that for the earlier part of the 20th century, in 11 out of 18 countries, more than 75 per cent of the electric utilities were foreign owned. By 1950, the percentage was identical for 10 out of 18 countries. Yet by 1970, ownership of electrical utilities turned on its head: foreigners controlled less than 10 per cent of electrical utilities in 17 out of 20 countries. In fact, in 15 countries all electrical utilities were in domestic hands, typically after nationalisation or expropriation. Our hypothesis is that the availability of funds, whether in the form of foreign direct investment or government expenditure, will also determine the ability of a country to develop its hydroelectric potential.

5. Data, model and empirical results

To test the hypothesis just set out, we first used a fixed-effect model. Fixed-effect models are designed to study the causes of changes within an entity, a country in our case. A time-invariant characteristic, such as the theoretical gross hydroelectric potential, cannot cause such a change because it is constant for each country through time. Thus, we can study the effects, within each country, of having alternative energy sources, of the size of its urban population, the capacity of its government to finance public works or how attractive a country is for foreign investors.

We use dummies for oil and coal producers to account for the natural endowment effect. We obtain these data from multiple sources including Rubio et al. [1], Yáñez et al. [25] and the United Nations *World Energy Supplies* series [30,31]. Urban population will be used to gauge the effect of demand and it comes from the MOXLAD database [32] interpolating where needed. Finally, the country capacity to finance infrastructures, such as dams or the electrical network, may depend on central government revenues or its attractiveness for foreign capital – implicitly assuming that private national funds could not afford such investments. Both central government revenue and foreign direct investment (FDI) are available at MOXLAD database [30], although FDI series partial coverage may probe problematic.

In all the models fitted, the dependent variable is the logarithm of total hydropower consumed in a country – Log(*hydro*) – (in GW h). The first model just takes into account the natural endowment. The domestic production of petroleum enters the equation as a dummy variable – *Pdummy* – which takes the value of one if the country produced oil and zero otherwise, likewise for coal production – *Cdummy*. Mathematically this is

$$\text{Log}\,(hydro) = c + b_{1t}Pdummy + b_{2t}Cdummy + u_i + e_{it} \tag{1}$$

where u_i and e_{it} are the errors terms, c is the constant. Therefore the sum of the estimated values of $c+b_{1t}$ is the fitted estimate of the log of hydroelectricity consumption.

The second model includes the demand effect by introducing the urbanisation rate (Urb) and the urbanisation rate squared (Urb^2),

$$\text{Log}\,(hydro) = c + b_1Pdumy + b_2Cdummy + b_3Urb + b_4Urb^2 + u_i + e_{it} \tag{2}$$

The third equation fitted adds the government central revenue (in logs) (log(GR)),

$$\text{Log}\,(hydro) = c + b_1Pdumy + b_2Cdummy + b_3Urb + b_4Urb^2 + b_5\log(GR) + u_i + e_{it} \tag{3}$$

Finally, the effect of foreign direct investment (in logs) (log (FDI)) is added in the fourth specification,

$$\text{Log}\,(hydro) = c + b_1Pdumy + b_2Cdummy + b_3Urb + b_4Urb^2 + b_5log(GR) + + b_6\log(FDI) + u_i + e_{it} \tag{4}$$

All fitted specifications introduce yearly dummies to account for time effects. In each specification, we include a dummy for each shift of the intercept, which is more realistic than including the time effects by a time trend that will assume the shift is the same in each year over a century. For each of the empirical estimations in Table 5 the coefficients of the regressors are all jointly significantly different form zero. Our models are significant.

Contrary to our initial hypothesis, having additional forms of energy in a territory does not delay the development of hydroelectricity. According to our estimations, if a country become an oil producer its hydroelectricity surges in parallel by a huge amount.

Table 5
Empirical results.

	Fixed effects models				Random effects models			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable: Log(hydro)								
Gross theoretical potential (log)					0.523***	0.547***	0.554***	0.544***
Coal producer	−0.406*	−0.475**	−0.251	1.742*	−0.179	−0.271	0.842***	0.504***
Oil producer	2.406***	2.302***	2.372***	2.927***	2.222***	2.133***	−0.373***	−0.180*
Urbanization rate		0.0298***	0.0203***	0.00906		0.0313***	0.0227**	−0.0z199
Urbanization rate squared		−0.000275***	−0.000141**	1.32e−05		−0.000279***	−9.03e−05	0.000216*
Government Revenue (log)			0.0449	0.00101			0.323***	0.404***
Foreign direct investment (log)				0.0402*				−0.000702
Constant	−1.298***	−1.770***	−1.398***	−0.839	−3.832***	−4.453***	−3.320***	−2.788***
Observations	1,593	1,593	1,498	599	1,593	1,593	1,498	599
Number of countries	20	20	20	20	20	20	20	20
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-sq within	0.907	0.908	0.910	0.920	0.907	0.908	0.886	0.889
R-sq between	0.0256	0.0164	0.0563	0.478	0.371	0.374	0.768	0.891
R-sq overall	0.540	0.534	0.562	0.689	0.701	0.707	0.859	0.891

Standard errors in parentheses.

*** $p < 0.01$.

** $p < 0.05$.

* $p < 0.1$.

This is consistent with the Jevons paradox in which cheaper energy – through increased availability of energy resources rather than by efficiency gains – results in larger energy consumption. In the case of the coal producers, we obtain a significant positive effect on two of the specifications but also a negative sign in the two simpler models. These differences in the two fossil fuels may be due to the facto differences in the amounts in which both exist in the region, as explained above, and their overall capacity to alter an economy. Oil production tended historically to be much larger than the domestic needs while coal production was unable to meet domestic demand. Let us analyse the rest of the results before discussing these initial results further.

As expected, demand appears as a strong driver of hydroelectricity consumption. On average, each additional percentage point in urbanisation increases hydroelectricity consumption by 2 per cent. The negative sign in the quadratic form implies that the impact decelerates at higher levels of urbanisation, but it also informs us that the turnover takes place after 100 per cent in all specifications.[6] Holding the rest constant, a country will tend to consume more hydroelectricity as its urban population grows.

Hydropower increases by 0.04 per cent for every one per cent increase in government revenue and foreign direct investment, but the result is only statistically significant for the latter in our fixed effect estimation.

The first four specifications in Table 5 are unable to account specifically for unobservable country heterogeneity through the inclusion of country fixed effects. Such unobservable time-invariant country characteristics include, in addition to the natural endowment, for example, culture, history, response behaviour, and formal institutions that are not captured by available measures. These time-invariant processes can have effects on time-varying variables, but they are lost in the fixed effects model.

Specifications five through eight fit a random effects model that explicitly accounts for the effects of the different gross theoretical potential. A one per cent increase in the gross theoretical potential is associated with a 0.5 per cent increase in hydropower harnessed, holding the remaining independent variables constant. The rest of the coefficients tell the same basic story as the fixed-effects model except for the government revenue and foreign capital. In the random effects fitting for every one per cent increase in government revenue hydroelectricity increases 0.3 per cent, which is a statistically significant result. The impact of foreign direct investment becomes statistically non-significant.

In either case, the existence of alternative energy endowments works oppositely to what is expected – the more oil and coal there is, the more hydroelectricity is consumed. We could also argue that perhaps oil production made the country more urbanised, more attractive to FDI and generated additional revenues for the central government, all of which would favour the development of more existing hydropower resources. Demand appears as a strong driver – but with decreasing impact as urbanisation progresses – and of the supply factors only central government revenue seems to obtain a meaningful and statistically significant impact on the development of hydroelectricity. Feeble data on foreign direct investment, reducing the observations to a third, may be partially responsible for these results.

6. Conclusions

These pages offer a unique quantitative overview of the evolution of hydropower in Latin America during the 20th century based on a careful historical reconstruction of the available data. It is a history of uneven evolution across time and space: several world leaders – in absolute and relative terms, such as Brazil and Costa Rica – sit side by side with countries that have almost no hydraulic potential, such as Cuba or Haiti. Almost from the technology's introduction, hydropower was present in Latin America, and after a century of successive waves of development, the region utilises more hydroelectricity today on average than the rest of the world, both relative to primary energy and relative to other forms of electricity. While hydroelectricity progressively lost ground vis-à-vis other energy carriers in the rest of the world, it gained share in Latin America especially from the 1960s and, especially, after the oil crisis. This is true even discounting the effect of Brazil, the region's giant that historically generated over half of the region's hydroelectricity.

As mentioned, the differences in terms of hydroelectric potential within the region are huge. However, we found that the timing and degree of hydroelectricity development of different countries did not always reflect the availability of water flows. Apart from Brazil, some of the best-endowed countries come late to develop their potential, some still lagging behind (Peru and Colombia, in particular). Even among the worst endowed, some countries managed to generate more hydroelectricity starting with resources more meagre than others. The natural endowment limited the hydroelectric capabilities of some countries, but hydroelectric potential appears to be a necessary but insufficient condition to explain the individual historical advance of hydroelectricity generation in Latin America.

This historical regional overview contributes to a better understanding of how the current position of Latin America as a world hydropower leader came about. Nevertheless, it is worth remembering that Latin America is a low energy consumer region (the second smallest in the world!), which also applies to electricity consumption per capita. Hydropower, despite its large historical contribution to the regional energy basket, has the potential to continue being a leading power source in the region for years to come. However, rising ecological concerns may be as important as economic and technical constraints at the time of undertaking future hydrological projects.

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Appendix A. Data sources and series

Referring to hydroelectricity generation before 1925, Rubio et al. [1] stated that 'there is very little information regarding hydroelectric production in Latin America at this early stage; the closest in time is the one by the United Nations which produced an estimate of the hydroelectric production in Latin America by 1929'. The solution adopted by Rubio et al., was to use estimates by

[6] Because the quadratic ax^2+bx+c turns over at $x=-b/2a$. For example, our URB and URB^2 coefficients in (3) imply that the function turn over at $0.0203/(0.000141\times 2)\approx 7198$ per cent.

Table A1
Data sources.

Country	1900s–1930	1931–1949	1950–2005
Argentina	Tafunell (WES1929)	1931 E&L 1932–1943 CEPAL 1944–1949 E&L	WES+ESY
Bolivia	1914–1929 Tafunell (WES1929)	1933 DARMST 1937–1949 UN(SY)	WES+ESY
Brazil	Villela et al. [38] at 2891 h/year	1931–1938 Vilanova and Suzigan (1971) at 2891 h/year 1939–1949 CEPAL	WES+ESY
Chile	1900–1924[a]	1925–1949 CEPAL	WES+ESY
Colombia	Tafunell (WES1929)	1933 DARMST 1934.1949 CEPAL1956	1950–1959 WES 1980–2005 EIA
Costa Rica	1900–1909[b] 1909–1930 Tafunell (WES1929)	1930–1936[b] 1937 WES 1938–1950[b]	WES+ESY
Cuba	Tafunell (DARMST)	1933 DARMST 1937–1938 DARMST	WES+ESY
Ecuador	Tafunell (WES1929)	1933 DARMST 1937–1938 DARMST	WES+ESY
El Salvador	Tafunell (WES1929)	1937 WES1929–1950 1938 CEPAL 1948–1949 E&L	1950–1959 WES 1980–2005 EIA
Guatemala	Tafunell (WES1929)	1932–1949 CEPAL[c]	WES+ESY
Haiti	–	–	1972–2005 WES+ESY
Honduras	Tafunell (WES1929)	1937 WES	WES+ESY
Mexico	Tafunell (EHM1930)	1930–1931 CEPAL 1932–1949 EHM	EHM
Nicaragua	–	1937–1949 CEPAL	1950–1959 WES 1980–2005 EIA
Panama	–	–	
Paraguay	–	–	1968–2005 WES+ESY
Peru	Tafunell (WES1929)	1930–1949 CEPAL[d]	
Republica Dominicana	–	–	1950–1959 WES 1980–2005 EIA
Uruguay	–	1945–1949 CEPAL	WES+ESY
Venezuela	Tafunell (WES1929)	1937 WES1929–1950 1946–1949 CEPAL1956	WES+ESY

[a] Based on an estimate by M. Folchi (mimeo) using installed capacity working 4800 h. It is consistent with the working hours reported for Chile by CEPAL [4] and with the pluviometry data available for the period.
[b] Based on installed capacity data taken from Gonzalez Truque [36] and Fallas and Amador [37]. Where needed the stock of installed capacity was calculated from the sum of plants working at any time and forced to depreciate every 40 years. The figure obtained of installed capacity was estimated to work at 30 per cent capacity.
[c] The figure provided by CEPAL [4] corresponds to the total public electricity generation. By 1952, two thirds of such figure were hydropower generated, which is the share applied to the whole period.
[d] From 1930 to 1947 CEPAL [4] only reports the generation of about 70 per cent of the public companies, which were less than half of the total generation. We rescale the figure to an estimated total that match the levels reported for 1930, 1937 and 1938 by WES [31].

Tafunell [17] who projected backwards the hydroelectricity generation of 1929 using the stock of electrical generators of each country from 1907 to 1929 transformed into hydroelectric production using the factor found for 1929.

For the period before 1930, the base solution is mostly identical apart from the exceptions identified in Table A1. We use Tafunell's method, but in some cases, we chose an alternative level of hydroelectricity generation as the departing figure for the back-casting; in other cases, historical alternative estimates of generation or installed capacity existed and were used instead.

We reconstructed the data for the period 1931–1949 mostly on the basis of information provided by ECLAC [2,4] and the United Nations' *Statistical Yearbook* [33], also making use of, and contrasting with, national information where available, including additional secondary sources identified in Table A1. The gaps were filled using linear interpolation.

The figures on net consumption of hydroelectricity after 1950 are available from the United Nations *World Energy Supplies* series [28,29]. The contrast of these series with alternative domestic and international series published demonstrate that in some instances the data provided by the United States Energy Information Administration [5] proved to be more consistent from the 1980s; they are preferred.

The choices made for individual countries in the reconstruction of their series of hydropower are listed in Table A1.

List of principal sources and abbreviation used:

CEPAL: United Nations. Economic Commission for Latin America and the Caribbean (UN. ECLAC/CEPAL) La Energía en América Latina [4].
EHM: Mexico, Instituto Nacional de Estadistica y Geografía (INEGI) [34].
DARMST: Darmstadter, [3].
E&L: Etemad and Luciani [16].
EIA: United States of America, Energy Information Administration [5].
UN/WES: World Energy [31].
UN/ESY: Energy Statistics Yearbook [35].
UN/SY: Statistical Yearbook [33].

Appendix B. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.rser.2014.05.068.

References

[1] Rubio MdM, Yañez C, Folchi M, Carreras A. Energy as an indicator of modernization in Latin America, 1890–1925. Econ Hist Rev 2010;63(3):769–804.
[2] United Nations. Economic commission for Latin America and the Caribbean (UN. ECLAC/CEPAL). Washington DC: Estudios sobre la Electricidad En America Latina; 1962.
[3] Darmstadter J, Teitelbaum PD, Polach JG. Energy in the world economy; a statistical review of trends in output, trade, and consumption since. Baltimore: Published for Resources for the Future by the Johns Hopkins Press; 1971; 1925.
[4] United Nations. Economic Commission for Latin America and the Caribbean (UN. ECLAC/CEPAL). La Energía en América Latina. Estudio realizado por la Secretaría de la Comisión Económica para América Latina, Instituto de Desarrollo Económico del Banco Internacional de Reconstrucción y Fomento, Washington DC; 1956.
[5] U.S., Energy Information Administration. 〈http://www.eia.doe.gov/emeu/international/contents.html〉; [visited on June 2010].
[6] Krausmann F, Haberl H. The process of industrialization from the perspective of energetic metabolism: socioeconomic energy flows in Austria 1830–1995. Ecol Econ 2002;41(May):177–201.
[7] Steward FR. Energy consumption in Canada since confederation. Energy Policy 1978;6(3):239–45.
[8] Malanima P. Energy consumption in Italy in the 19th and 20th centuries: a statistical outline, [Naples]: Consiglio nazionale delle ricerche Istituto di studi sulle società del Mediterraneo; 2006.
[9] Hunt L, Ninomiya. Y. Primary energy demand in Japan: an empirical analysis of long-term trends and future CO emissions. Energy Policy 2005;33:1409–24.
[10] Gales B, Kander A, Malanima P, Rubio MdM. North versus south: energy transition and energy intensity in Europe over 200 years. Eur Rev Econ Hist 2007;11(2):219–53.
[11] Rubio MdM. Energía, economía y CO_2: España 1850-2000. Cuadernos Econ ICE 2005;2(70):51–71.
[12] Kander A. Economic growth, energy consumption and CO_2 emissions in Sweden 1800–2000. Lund studies in economic history 2002:19.
[13] Fouquet R, Pearson P. A thousand years of energy use in the United Kingdom. Energy J 1998;14:1–41.
[14] Warde P. Energy consumption in England and Wales. Naples: Consiglio Nazionale della Ricerche; 2007; 1560–2004.
[15] Schurr SH, Netschert BC. Energy in the American economy, 1850–1975: an economic study of its history and prospects. Baltimore: The Johns Hopkins Press; 1960.
[16] Etemad B, Luciani. J. Under the direction of Paul Bairoch & Jean-Claude Toutain. World Energy Production 1800–1985. Paris: Centre National de la Recherche Scientifique; 1991.
[17] Tafunell X. La producción hidroeléctrica en américa Latina, 1907–1930: un apunte para su quantificaciónn. In: Rubio MdM, Bertoni R, editors. Montevideo: Energía y Desarrollo en el largo siglo XX: Uruguay en el marco Latinoamericano; 2008. p. 73–90.
[18] Tafunell X. La revolución eléctrica en América Latina: una reconstrucción cuantitativa del proceso de electrificación hasta 1930. Revista Hist Econ-J Iberian Lat Am Econ Hist 2011;29:327–59, http://dx.doi.org/10.1017/S0212610911000140.
[19] Rubio MdM, Folchi M. Will small energy consumption be faster in transition? Evidence from the early shift from coal to oil in Latin America Energy Policy 2012;50:50–61 (November).
[20] Young LL. Summary of developed and potential waterpower of the United States and other countries of the World 1955–62, Geological Survey Circular 483, Washington DC; 1964.
[21] World Energy Council. 2010 Survey of Energy Resources, London; 2010.
[22] Int J Hydropower Dams, World Atlas; 2009.
[23] International Copper Association (ICA). Renewable energy for electricity generation in Latin America, Santiago de Chile; 2010.
[24] Rubio Md M. The role of Mexico in the First World Oil Shortage: 1918–1922 an international perspective. primavera: Revista Hist Econ-J Iberian Lat Am Econ Hist, 2ª época, N° 1, Año XXIV; 2006; 69–96.
[25] Yáñez C, Rubio MdM, Jofré Jy, Carreras A. El consumo aparente de carbón mineral en América Latina, 1841-2000. Una historia de progreso y frustración. Revista Hist Ind, N.° 53, Año 2013;XXI(3):25–76.
[26] Donald W Jones. Urbanization and energy use in economic development. Energy J 1989;0(4):29–44.
[27] Bartolomé I, Laciotti N. Comparado de los sistemas eléctricos en España y Argentina, 1890–1950. Estrategias globales y experiencias divergentes de la electrificación en dos países de industrialización tardía, Documento de Trabajo no 660/2011, Fundación de las Cajas de Ahorros, Madrid; 2011.
[28] Bertoni R. Energía y desarrollo. La restricción energética en Uruguay como problema (1882–2000). Tesis Doctoral, Montevideo, Universidad de la República; 2010.
[29] Hausman WJ, Hertner P, Wilkins. M. Global electrification. Multinational enterprise and international finance in the history of light and power 1878–2007. New York: Cambridge University Press; 2008.
[30] United Nations . World energy supplies in selected years 1925–1950, New York; 1952, Statistical papers series J, no 1.
[31] United Nations . World energy supplies 1950–1974, New York; 1976, statistical papers series J, no 19.
[32] The Montevideo-Oxford Latin American Economic History Data Base, 'MOxLAD', 〈http://moxlad.fcs.edu.uy/en.html〉.
[33] United Nations (1948, 1952, 1955, 1956 y 1957) Statistical yearbook. New York.
[34] Mexico, Instituto Nacional de Estadistica y Geografía (INEGI). Estadísticas Históricas de Mexico 2009, Mexico DF; 2010.
[35] United Nations. (various years 1970s-2000) Energy statistics yearbook, Department of International Economic and Social Affairs, Statistical Office (previously known as Yearbook of World Energy Statistics).
[36] Gonzalez Truque H. Censo cronológico del desarrollo de la Industria Hidro-Eléctrica en Costa Rica. Tesis. San José; 1948. Apendice A.
[37] Fallas CE, Amador yJL. Historia de la Electrificación en Costa Rica 1883-1992 (Borrador), Oficina de Patrimonio Histórico y Tecnológica. Dirección de Gestión Cientifica y Tecnológica ICE.
[38] A. Villela Villanova, W. Suzigan, S.R. da Silva, and M.M. Santos (1971): Aspectos do crescimento da economía brasileira, 1889-1969, Rio de Janeiro, Fundação Getúlio Vargas.